DOCUMENT RESUME

ED 255 366 SE 045 452

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TITLE Cognitive Processes and Students' Misconceptions in Science.
PUB DATE [84]
NOTE 22p.; Paper presented at the Annual Meeting of the Northeastern Education Research Association (Ellenville, NY, October 25, 1984).
PUB TYPE Speeches/Conference Papers (150) -- Reports - Descriptive (141)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Cognitive Processes; *Concept Formation; *Elementary School Science; Elementary Secondary Education; Science Education; *Science Instruction; Secondary School Science; Water
IDENTIFIERS *Misconceptions

ABSTRACT

Several categories of misconceptions which appear to be emerging across studies are discussed. They include: mis-perceptions; stunted conceptions; mis-translations; confused conceptions; lost conceptions; and true misconceptions. True misconceptions are metaphors and analogies which represent truly complete systems of explanation but are conceptually wrong; for example, many adults whose models for the way a thermostat controls the furnace assume an accelerator metaphor. A common elementary science lesson on the water cycle is also examined in detail, focusing on places where children might go wrong in their understanding, and on how underlying cognitive processes might be connected to these difficulties. In addition, instructional implications arising from the discussion of cognitive processes as well as some further research which is needed to clarify these implications are addressed. One implication noted from a consideration of the cognitive processes required in the elementary science lesson is to teach it to much older children, whose working memory capacities can maintain and manipulate all the necessary factors. For young children, the lesson clearly overtaxes their abilities to represent mentally the events demonstrated, to construct functional rules for those events, to coordinate rules into a dynamic model, and to manipulate that model to explain unseen real-life events. (JN)

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Cognitive Processes and Students' Misconceptions in Science

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A paper presented at the annual meeting of the
Northeastern Education Research Association
October 25, 1984
Ellenville, New York

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The science education literature is now full and running over with examples of every possible kind of misconception (eg., Driver and Erickson 1983), across age groups (Kamii and Derman 1971; McCloskey 1983) and in domains from photosynthesis (Roth et. al. 1983) to paths of acceleration (Viennot 1979). We already know that science instruction takes up little time in elementary classrooms (Rosenshine 1980) and that many teachers are uncomfortable and ill-prepared to teach it (Welch 1981). Yet, even the best students of the best teachers are going wrong (Easley 1982), so the problem is not only one of the quantity or quality of teaching. In fact, the current difficulties seem a frustrating set of variations on the old saw, "I taught it, but they didn't learn it— ignored it, lost it, encapsulated it, etc."

The logical next step for concerned educators might be the step into classrooms in an effort to answer the question: "What can we do differently in classrooms to prevent and/or fix these misconceptions?" Yet that question in itself implies that we can clearly identify and understand the mechanisms by which children come to be wrong about a particular science concept. To use Piaget's description of the preoperational child as an analogy: what we have out of the good, detailed descriptive work already done are fairly clear snapshots of the endpoints children reach. However, if we focus on the endpoints without constructing mental explanations for the processes which connect those endpoints, we may fail in our efforts to predict and prescribe in order to intervene in the classroom.

As Novak (1983; see also Hills 1983) points out in his introduction to the Proceedings of the 1983 Cornell Conference, it is important to be clear about the sources of the different misconceptions. If we can pinpoint the mechanisms which might engender each, we gain not only in our ability to prescribe and test domain-specific classroom interventions, but also in our ability to construct coherent explanatory mental models and to examine the ways in which the factors in each integrate, contradict and interact. For example, Posner and Strike (1982) and others (Siegler 1983; Case 1978) have outlined some similar aspects of an overall model of conceptual change. I want to suggest that what is needed is an application of their approach to particular domains in order to integrate what Driver and Erickson (1983) have termed theory-driven and problem-driven work (much as the preoperational child must coordinate and integrate two aspects of the same task). I see

these two aspects as inseparable in an essential way: theories inevitably drive our examination of any problem as soon as we begin to conjecture about how to solve it; and there would be no need for theories at all, were we not problem-driven by the massive failures of particular science lessons.

In this paper, I first consider several categories of misconceptions which appear to be emerging across studies. Next, I examine in detail one common elementary science lesson on the water cycle, with attention to the places where children might go wrong in their understanding, and how underlying cognitive processes might be connected to these difficulties. Finally, I suggest some instructional implications arising from the discussion of cognitive processes, and some further research which is needed to clarify these implications.

TYPES OF MISCONCEPTIONS

One of the most salient misconceptions is the perceptually-driven: overwhelming sensory data which seems to prevent the student from assimilating a different model into cognitive structure, in spite of our best efforts to teach it. This may take the form of an overwhelming number of features/factores/distractors in the information to be processed, so that children cannot attend to the relevant ones (eg., Siegler and Liebert 1974) or lose information from working memory (Case 1984). It may involve the inability to de-center from one's own perspective on an event; although Piaget (1958) first reported this inability as characteristic of young children, it now appears that adults who are novices in a domain, or who lack an underlying conceptual understanding, are greatly affected by perceptual features of an event or task (eg., McCloskey 1983; diSessa 1982; Clement 1983; Viennot 1979). These misconceptions might be called mis-perceptions, because the student fails to go beyond the difficulties encountered at the perceptual level.

Next, children construct stunted conceptions: limited viewpoints or inadequate systems which focus on one factor, or only one part of a larger system (eg., Siegler 1981; Case 1978; Piaget 1980). These viewpoints are often logically coherent (Smith and Murray 1984; Clement 1983), but limited and thus incorrect. They appear to be stunted at the level which Piaget (1977) called the logic of functions, and Siegler (1983) terms rule use. The most common explanation has been that the student's working memory space is inadequate for maintaining all the necessary factors and manipulating them at the same time (Case 1984).

Minstrell (1983) has suggested that we need to look carefully at the

representations we offer students — pictures, demonstrations, symbols,etc. Students' problems in this area might be called mis-translations, failures in the linking of external representations to an underlying conceptual representation. In the mathematics domain, Hiebert (1984) has identified three sites where students go wrong in interpreting external representations: 1) in connecting the symbol to the concrete referent; 2) in connecting the procedures used to manipulate the representation to the underlying conceptual model; and 3) in connecting the result of the symbolic manipulation to the real world events, so that the answer makes sense. In science lessons, children may connect an incorrect referent or make no connections at all; they may construct a literal translation of the pictures or demonstrations they see, without understanding the complete model; or they may learn the series of steps presented in the lesson without testing them against or connecting them to actual events in their own lives.

When children attempt to coordinate all the pieces which might pertain to any particular lesson, they sometimes end up with confused conceptions: overlapping language schemes. number schemes, relevant and irrelevant factors which intrude into the child's construction of the correct model. For example, Solomon (1983) has examined how children's everyday language confuses their understanding of scientific definitions for the same words. Murray and Markessini (1982) found that connotations and denotations of words affected children's concepts about weight. Strauss (1983) documented the way in which highly-practiced arithmetical procedures for addition interfere with understanding heat and temperature. These tangled hierarchies (J. Anderson 1983) of concepts appear to be some of the most difficult misconceptions to correct, because there are so many pieces from so many sources involved.

In what we might think of as the true misconceptions category are metaphors and analogies which represent truly complete systems of explanation but are conceptually wrong. For example, Gentner (1984) reports adults whose models for the way a thermostat controls the furnace assume an accelerator metaphor. Hewson's (1983) work on conceptions of heat as the flow of particles is another example of this type of misconception. These metaphors often mimic historical developments in science, and because of their inherent coherence are difficult to correct.

Finally, there are some ideas which children have for which it is not

clear exactly what has gone wrong (Hills 1983), but the retrieval of whatever knowledge they have appears to fail them in part or totally. For example, in the Osborne and Cosgrove study (1983) of children's knowledge about the water cycle, it appears that children have some concepts structured at some levels, but are able to retrieve only odd bits -- key words, images, pieces of temporal schemes, and not much more. These may result from mistranslations or confused conceptions; for whatever reasons, they are lost conceptions for the child, ie., children are unable to retrieve the knowledge they once had stored in long term memory.

Having reviewed several kinds of misconceptions which children have, in the next section I examine the domain of water cycle knowledge in detail from the child's point of view, and suggest how particular cognitive processes may explain difficulties in the child's construction and retrieval of knowledge. For my purposes here, I will assume a "good" teacher and an "attentive" child, and will not consider the interactive effects of all the children in the class. What I want to demonstrate and argue is that in many elementary science lessons, (eg., Abruscato et. al. 1980; Holmes et. al. 1983) there are ample opportunities for the child's construction of misconceptions, even if we assume a "good" teacher and "attentive" child in the classroom.

COGNITIVE PROCESSES DURING INSTRUCTION

Consider a six-year-old in a first grade classroom with at least twenty-five other children and one committed teacher. Whether this is a science lesson or not, the teacher will probably be at the front of the room (Hoetker and Ahlbrand 1969) with children listening at their desks or in a circle on the floor. The teacher usually begins the lesson by discussing rain and rainstorms with the children and eliciting their ideas. S/he probably uses the question-response-evaluation form of classroom interaction which is so common (Cazden 1984). What sort of cognitive processes are activated for the child?

Lesson Introduction

One might assume at the least that the child will retrieve various episodic memories of storms, with thunder, lightning and winds being the most salient aspects. These may be stored as temporal schemas (Rumelhart and Ortony 1977) or the child may have already have made some causal links based on co-occurrences (Sedlak and Kurtz 1981). In addition, there may be some feelings of fear or awe, and a conclusion about the power or force possible in storms. Children may also have some pieces of verbal explanations from parents and teachers and some visual images of preschool lessons (because I want to con-

sider the kettle/pan of ice demonstration in some detail later, I will assume here that the child has not seen that lesson).

For the child participating in the discussion, some or all of these tangled hierarchies (Anderson 1983) may be retrieved: overlapping networks of images, words and temporal schemas which are cued by the teacher's discussion and which fade in and out of working memory, as the child monitors the teacher's talk and other children's responses. Althought this sort of knowledge organization may be characteristic of young children especially (Mandler 1983), it may be true for novices of all ages (see Stevens and Collins 1979; Reif 1983; Larkin et. al. 1980), in that knowledge is not yet organized in hierarchical and conceptual relationships.

The teacher leading this discussion may not be aware that all of this information is already activated for each of the twenty-five children. Even if s/he were, the task of probing and diagnosing each child's current knowledge state would be overwhelming, in terms of time and energy involved. In the next part of the lesson, s/he may choose to assume as little as possible about children's knowledge, so as not to leave any children behind. More importantly, the teacher's guide will not suggest at any point that children's ideas must be considered or corrected.

Lesson Demonstration

The usual demonstration of the water cycle for children includes a teakettle with boiling water, a pan of ice held over the escaping vapor, and the gradual collection of drops of water on the underside of the pan. What sort of cognitive processes might go on, as the child watches this demonstration?

Perceptual Processes: Visual

First, the perceptual demands are considerable and opportunities for misconceptions are many. The child must watch the events, attend to the teacher talk explaining the events, and coordinate the two so as to construct meaning. The most visually salient features are the boiling water, clouds of vapor, and pan of ice. If children are easily distracted by many salient features and have limited working memory space (Siegler 1983; Case 1984) one can imagine the difficulty they have switching attention back and forth among the water, rising vapor, pan and the teacher's explanation. One can see how easily children might misperceive the rising vapor as the visually similar "smoke" (Osborne and Cosgrove 1983) and begin constructing misconceptions based on fire and burning. Indeed, if the child attends to the teacher's explanations

at the same time, s/he learns that heat is what makes the water boil and the vapor rise, so the connection to smoke makes sense. The child's current schema for understanding heat and temperature is probably based on a caloric and not a kinetic model, so children may conclude that heat particles are escaping into the air; Osborne and Cosgrove (1983) do report that children believe that the bubbles in the boiling water are heat. Already we have the beginnings of misconceptions, based on misperceptions of the visual events and the overlapping of several schemes in the child's attempt to construct meaning.

Perceptual Processes: Auditory

Let us turn to the auditory processing of teacher talk to which the child must also allot attention. Even if we assume that the child's and teacher's cultural expectations for language use match (Cazden 1984), there are several opportunities for confused conceptions in this lesson. Children are already attending to the visually salient features of the lesson; they may be switching attention back and forth and tuning in and out of the verbal explanation. We know that teachers often use paralinguistic cues (such as facial expressions, intonation, and gestures) in order to emphasize important parts of the lesson (Green and Smith 1982). If the child's attention is on the boiling water at the time, s/he may not catch the causal connections being made or factors being emphasized. As Lovell (1979) suggests:

> ... a great deal of information given orally can overtax short term memory, as can some problem-solving tasks where the pupil has to hold in store some information while simultaneously processing other data.

In addition to the perceptual demands of processing, children's everyday understandings of the words used may interfere or cause confusion (Solomon 1983). We have already considered how the child's concept of heat may intrude. Terminology such as the "strength" of the sun with its connotations of force and power may result in the child's belief that water can only evaporate on hot sunny days in the summer. The explanation that rain occurs when drops of water are "too heavy to float" in the air may activate the child's notions of weight or gravity and result in confusion about how drops become heavier or lighter in the air.

Beyond these everyday words, the child hears totally new terminology such as evaporation, condensation, and precipitation. For the child who is struggling to attend to both the visual and the auditory information, it is no wonder that these terms remain stored in what Larkin (1983) calls flashcard

memory, unconnected conceptually and retrievable only when the context exactly matches (Osborn and Cosgrove 1983).

Two other aspects of the language used may add to the child's difficulties. Descriptive words for dimensions in the lesson — eg., hot and cold— are used in their global, undifferentiated form; children are not helped to consider comparative aspects of the event, eg., to consider what would happen if the water were hotter or colder. Thus children may construct stunted conceptions of the process, in which only hot days or cold days are of concern. Finally, even the temporal nature of the event may be difficult for children to abstract, because the processes of evaporation and condensation occur almost simultaneously in the demonstration. If the teacher's words have to carry the temporal sequence (eg., first, next, then...) children's chances of attending to, noticing and connecting those temporal markers to the events themselves appear unlikely.

We have looked at the perceptual demands on the child's cognitive processes in terms of visual and auditory processing, and seen that the number of visually salient features, the requirements for processing in two channels at once or for switching attention back and forth between channels, and the language used in this lesson provide many opportunities for the child to construct misconceptions. Next, let us consider the mapping of this external, concrete representation onto the child's own mental representations at Hiebert's (1984) three sites.

Representations: Site 1

Simply in terms of understanding what the concrete objects themselves represent (site 1), there are many opportunities for children to mis-translate. Water in streams, ponds, puddles or the ocean does not boil as does the water in the demonstration. Children may conclude that the process of evaporation which the boiling water and water vapor are representing takes place only in school, or at other times and places outside of school. Clouds of water vapor rising upward are not commonly visible even on sunny days; children may believe the literal demonstration and conclude that no water vapor is in the air (in spite of being told in the lesson that it is invisible). Again, children may translate the pan of ice literally and expect that clouds contain chunks of ice which melt to cause rainfall (Smith 1982).

The spatial and temporal aspects of the concrete representation are additional sources of mistranslations for children. The teakettle and pan of ice may be no more than two feet apart; yet children are expected to map this distance onto actual spatial differences of thousands of feet, between a lake

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and the clouds overhead, for example. The demonstration events take a matter of minutes in the classroom; the invisible actual events which the child is asked to construct occur over longer periods of time and are inaccessible for the child's comparison. (Even those activities which ask children to mark the levels of water evaporating in the classroom occur over days and require children to maintain a mental representation of an invisible process during that time.) So, simply in terms of the child's connection of external representations to their real world counterparts, this lesson offers many sites where mistranslations and resulting confused conceptions can be made.

Representation: site 2

At site 2, the connection of the manipulation of the external representation to some underlying conceptual model, more difficulties arise. As Collins (1982) has demonstrated in his tutorial models with adolescents and adults, an appreciation of the many factors involved in the rainfall cycle and their interactions is a hard-won construction. Because of the limited working memory space young children may have, their attention may be focused on one factor (eg., heat) or may switch back and forth between factors. However, even if they are capable of constructing what Collins (1980) calls a functional model, given the dangerous nature of the event, children have no way to act on the objects in order to manipulate factors and watch the process occur with some regularity. Without this active problem solving and testing of theories-in-action, (Karmiloff-Smith and Inhelder 1975), which enables the child to consider possibilities, construct simple one-factor models of what is true and regular, and to delete what is not true and not regular (Piaget 1983), children are unable to construct even the functional causal relationships of which we know they are capable at even earlier ages than first grade (Siegler and Liebert 1974; Sedlak and Kurtz 1982).

For example, Stevens and Collins (1979) have reported several kinds of "bugs" which older students' models of the evaporation scheme of the rainfall cycle contain. Students sometimes limit models to one factor (what I've called stunted conceptions), or may have rules for several factors but fail to coordinate them into one working model, or may fail to think through the implications of the model and thus end up contradicting themselves (what I've called confused conceptions). We have seen how difficult it might be for children to construct even one-factor functional rules from the external representations; yet elementary science lessons commonly assume that young

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children can and will construct the dynamic conceptual model involving the coordination of both the evaporation and condensation schemes into what Collins (1982) calls a runnable mental model (and what Piaget calls a reversible schema).

Consider the cognitive processes involved in constructing such a mental model for evaporation alone. First, children would need to establish functional rules for factors such as water temperature, air temperature, and relative humidity; the latter concept requires already that the child can construct and chunk as a manipulable whole, the ratio relationship of water in the air/ capacity of the air to hold water, an ability which is far beyond first graders (Piaget 1958; Siegler 1983). In the classroom lesson demonstration, the most salient of these factors is the temperature of the boiling water; the air temperature is confounded with the temperature of the ice, and the relative humidity is mentioned only in passing as a "holding" capacity.

Next, children would have to construct a mental model for the simultaneous interactions of these factors, based on the classroom demonstration. We have already considered some of the problems children might have in mentally representing even the temporal scheme for that demonstration. We know, for example, that even adults have difficulty manipulating mental images (Cooper and Shepard 1978). The ability to abstract a conceptual model in which the three factors vary simultaneously would tax the child's working memory far beyond its capacity to maintain and manipulate items. Thus, even for evaporation, itself only one of the two coordinated aspects of the complete cycle, children's mental models are unlikely to be conceptually complete.

Perhaps in an effort to support children in their attempts to make sense of these concrete representations of the water cycle, elementary science lessons often provide implicit metaphors of the kind Collins (1982) has described in his students. Air can "hold" water like a container; it "absorbs" water like a sponge; it "collides" with colder air, cools and the water drops become "too heavy" and fall as rain. These and other metaphors (see Collins 1982), although well-intentioned, provide yet another opportunity at site 2 for children's understanding to go astray. For example, Osborne and Cosgrove (1983) report that children believe water on a plate is absorbed into the plate; one can see how a general sponge metaphor might be generalized to include other objects as well.

Children also construct their own incorrect metaphors; for example, in the same study, children suggested that condensation occurred because the

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coldness of the glass of ice water "attracted" water molecules from the air. A general model in which water drops are attracted into the warm air and attracted back to cold objects could easily be constructed from the kettle/pan demonstration we have been discussing. Similarly, children suggested that water condensing on the glass was like sweat and was seeping through the glass from the inside. In these analogies, one can see children's attempts to retrieve what may be irrelevant knowledge (Anderson 1983) in order to explain and assimilate the observable concrete events (Piaget 1983); they appear unable to maintain the conceptual model of invisible drops of water in the air and to manipulate that model mentally in order to generate explanations. Thus, at best, the mental models which children construct from this demonstration may be the kind of true misconceptions (ie., complete models which are incorrect) I suggested earlier. At worst, they may be pieces of such models which remain unconnected and contradictory in what Lawler (1981) has called microworlds, or confused conceptions in which many different schemes are retrieved and overlap each other in the child's mental model.

Representation: site 3

In the last of Hiebert's sites where children can go wrong in connecting external representations to conceptual knowledge, he suggests that children must be able to test the results of their conceptual theories in the real world, to see if they make sense. We have already seen the difficulties children have in explaining events such as the condensation of water on a glass of ice water. How well would they do in connecting the classroom demonstration with the conceptual knowledge constructed from it and the real world of rainstorms?

As one might expect, due to the inaccessibility of events in the world of actual rainstorms, children's efforts to link them to school models of evaporation and condensation might run into trouble. For example, they might conclude that evaporation doesn't happen around where they live, because the water in ponds and oceans never boils. They may conclude that rain falls in their neighborhood because of thunder and lightning (their original conceptions), due to the fact that there are no mountains to cool the air. They might conjecture that fog is really smoke because it occurs close to the ground and not high up in the sky where the air is "cold enough" to form clouds. They may wonder why some clouds bring rain and others don't, if all clouds are high up in the sky and all clouds are made of water; their fall back explanation again may include their own original ideas, eg., lightning.

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Another difficulty in mapping the classroom model onto the real world arises because for the classroom model, the salient aspect of the process (what Piaget calls the affirmation, 1980) is the violent boiling away of the water; the condensation of water is less noticeable and the process is more difficult to construct mentally. On the other hand, in the real world of rainstorms, the salient aspect of the process is the rainfall itself; the evaporation aspect is difficult to imagine and construct mentally (what Piaget calls the negation, 1980). Thus, the two coordinated aspects of the complete cycle are differently salient in the two cases, and children may never see the two as related; they may maintain one model for the boiling in the classroom demonstration, and one model for the rainfall, without realizing that the two must be coordinated.

It is at site 3 that children encounter major stumbling blocks, because they have no way to test the implications of their models in the real world of weather. For example, one teacher's guide (Holmes 1983) suggests that if children's answers on the unit test are incorrect, they should re-read the text. As Osborne and Cosgrove (1983) assert,

> If scientific knowledge is to be learnt as anything but isolated knowledge, it is so important that models can be tested by pupils, that they are tested against reality, and that they are related to real life experiences.

Retrieval

Given our examination of the cognitive processes necessary for young children to attend to, process and construct conceptual models of the demonstration commonly taught in elementary science lessons on rainfall, it is easy to understand why children retrieve verbal strings unconnected to conceptual understanding or pictorial images without underlying mental models (Gilbert et. al. 1982; Osborne and Cosgrove 1983). While some temporal schemes for the classroom events may be present, and some memory for words learned in the lesson may be retrievable in a flashcard fashion, for the most part children look like novices in many other fields (eg., Larkin et. al. 1980; Reif 1983): they are perceptually bound to the observable events; make exhaustive searches of declarative networks, retrieving both relevant and irrelevant features and models; flounder along dead ends because no conceptual constraints guide the searches; and evaluate plausibility as they search. Because conceptual knowledge is lacking, incomplete or unconnected, children's attempts to reconstruct memory are likely to fail (Bradshaw and Anderson 1982). All of this is time-consuming in the real life of classrooms; understandably, children and teachers

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often opt for recognition of visual models and production of appropriate words as evidence of knowledge construction.

IMPLICATIONS FOR INSTRUCTION

The clearest implication for instruction from our consideration of the cognitive processes required in this lesson is to teach it to much older children, whose working memory capacities can maintain and manipulate all the necessary factors. For young children, this lesson clearly over-taxes their abilities to represent mentally the events in the demonstration, to construct functional rules for those events, to coordinate rules into a dynamic model, and to manipulate that model in order to explain unseen real-life events.

Suppose we consider a similar lesson for older children. Cognitive psychologists (eg., Collins 1977; Siegler 1983; Case 1978) and science educators alike (Posner and Strike 1982; Anderson and Smith 1982) have suggested important features for instruction which is meant to encourage conceptual change:

1. As the pre-instructional level, teachers should help students to recognize their present schemas (eg., that thunder causes rainfall), and list questions that must be answered in order to test that theory.

2. At the perceptual processing level, teachers can check children's memories: what happened? what did you see? Siegler (1983) suggests that checks of encoding sometimes reveal failures to notice important features early on in a task.

3. At the classroom language level, teachers should carefully differentiate words which have everyday usages (eg., "strong") and the ways in which they are used in the science lesson; they should check children's underlying premises about concepts introduced peripherally to the main lesson (eg., heat). Teachers should help students differentiate global dimensions by modelling the use of words such as hot, hotter, hottest, and encouraging students to measure so that the dimension can be further differentiated.

4. At the level of functional rules, teachers should isolate single factors in complex models and encourage students to test each for functional relationships in the event under consideration. These relationships can be externally represented in the form of graphs, charts or pictures, but only if connections to concrete referents and the underlying conceptual model are made explicit.

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Relationships could be tested by careful case selection, as Collins (1982) has modelled — eg., are there always mountains where it rains? What about Kansas? Contradictions and anomalies play an especially critical role in children's theories (eg., Piaget 1980; Siegler 1983; Posner and Strike 1982; Anderson and Smith 1982). Teachers may highlight them via case selection, or may ask students to discuss and justify their theories to each other (Ames and Murray 1982; Easley 1984).

Teachers could ask children to predict and test in real world situations, eg., if the Challenger is scheduled to land and the surface is too wet, what can be done to speed up evaporation? If the local reservoir is running low during the summer months, how can we prevent more evaporation?

5. At the level of temporal/causal schemes, salient visual representations along the lines of Anderson and Smith's (1983) overheads might help children construct temporal sequences. Teachers' use of temporal words such as first, next, then, and causal words such as if, because might highlight and support encoding of conceptual relationships.

6. At the logical/conceptual level, teachers could help children to construct constraints on their mental models, so that when they retrieve information or use it to reason about a problem, their searches are constrained by principles about the domain (Piaget 1983) and information is clustered (Larkin 1979; Greeno in press) with multiple access routes (J. Anderson 1983). For example, does the water which evaporates ever stop being water? Can some be lost in the process? Could it ever happen that water in a cloud never fell to earth again? If rain always comes from the sky, does it ever run out of water? If water always sinks into the earth, does it ever fill up?

Children's metaphors and analogies could be tested out at this level, too. For example, if condensation on a water glass is like sweat, why is the glass cold? A person who sweats is hot. Or, if the water diffuses through the glass to the outside, why doesn't the level of water inside go down?

Greeno (in press) suggests several ways to check for conceptual knowledge in a domain:

> 1. the generation of new procedures from principles underlying a domain (eg., how can we speed up/prevent evaporation?);
> 2. evaluation of others' responses (eg., does the sweat metaphor test out?);
> 3. extension to new tasks (eg., why does it rain in Kansas where there are no mountains?).

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7. At the metacognitive level, teachers can make explicit and model encoding and retrieval strategies, so that students can monitor their own strategies.

FUTURE RESEARCH

From this analysis of possible cognitive processes during instruction, in one elementary science lesson, it is clear that research into children's ongoing processing in classrooms (and out) is needed (Delacote 1980). Aside from the clues provided by descriptive studies and some of the results from classroom intervention studies (Anderson and Smith 1983), we really have very little idea about what children are attending to,,encoding or attempting to connect to their own experiences, during lessons. In the mathematics domain, Leinhardt (1983) and Peterson and Swing (1982) have started online and post-instructional interviews with children; in language arts, Morine-Dershimer and Tenenberg (1981) have examined children's memories for classroom events. This sort of work is much needed in the science domain, in spite of the difficulties entailed in collecting and analyzing the data.

Another area in which research is needed is that of children's assumptions about the task in school science instruction. L. Anderson's (1983) research on children's understandings of seatwork has shown that children are apparently unbothered by unclear purposes for many of the tasks they do. From teachers' emphases on the routines and procedures in science lessons (Smith and Sendelbach 1982), children might well conclude that understanding what has happened is not as important as doing the procedures correctly. Children's epistemological assumptions about what is learning, what is knowledge, etc., may be a critical aspect of what goes wrong in science lessons (see Strike and Posner 1982, for college students' assumptions in this area). If children believe that the task is to remember what happened and memorize the important words (Tasker 1981; Doyle 1981), then their strategies for remembering might be very different from those they use on their own friends, eg., while programming a Logo turtle.

Finally, the issue of teacher cognitions during instruction is an area which needs much attention, especially in the primary grades. Collins' (1982) model of Socratic dialogue and teaching by case selection requires a highly structured theory of the content domain. We know that teachers already avoid the discussion sections of activity-based science lessons (Anderson and Smith 1981), because they cannot maintain the knowledge structure while managing

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procedural routines and discipline demands. Dobey and Schaeffer (1984) found that teachers with better knowledge of the pendulum domain were more flexible and more willing to consider anomalous results. And teachers' abilities to diagnose misconceptions (Nussbaum 1979) and adapt instruction (what Hunt calls 'reading and flexing' 1981) are the basis upon which classroom intervention studies is being built (see Smith and Anderson 1983). What are teachers' epistemological assumptions about learning and knowledge? To what extent do these encourage children to be active meaning-makers or passive memorizers of authoritative information (Russell 1983)?

CONCLUSIONS

I have examined in some detail the cognitive processes required of children by a common elementary science lesson, and suggested ways in which cognitive processes might explain some of the kinds of misconceptions which children have in the domain of the water cycle. The lesson, as taught, offers children many places at which to go wrong and construct misconceptions, because it requires cognitive processing which young children are very unlikely to be able to perform. While some implications for instruction of older children have been suggested, I have argued that theoretically-driven classroom research in specific domains is necessary before intervention studies could be effective. Finally, I have outlined some of the kinds of classroom research being done and suggested areas in which research in science classrooms is needed.

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